Chapter 8: Wireless Sensor Networks

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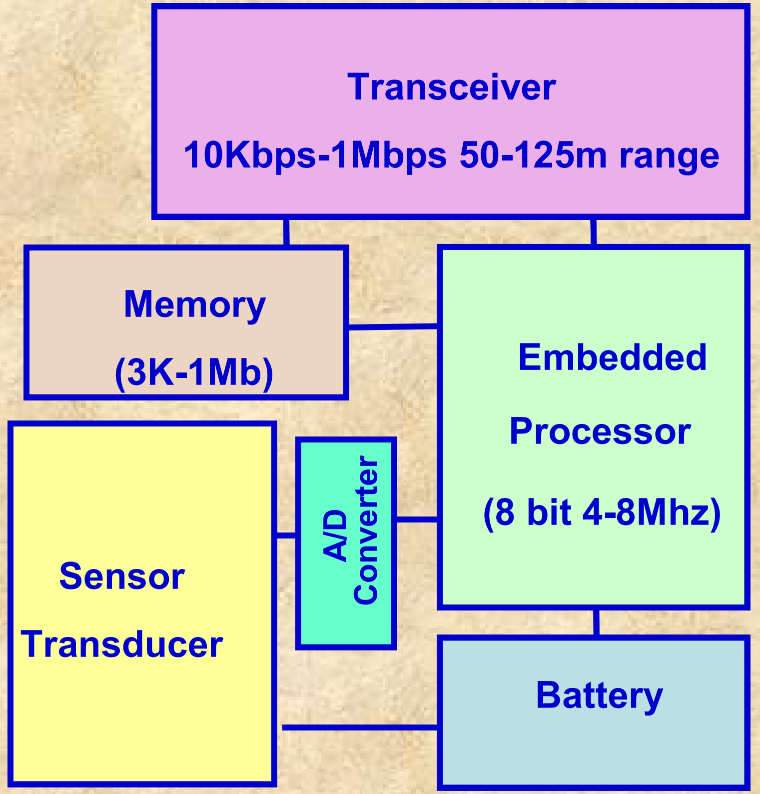
Introduction

- **Wireless Sensor Networks can be considered as a special case of ad hoc networks with reduced or no mobility**
- **WSNs enable reliable monitoring and analysis of unknown and untested environments**
- **These networks are "data centric", i.e., unlike traditional ad hoc networks where data is requested from a specific node, data is requested based on certain attributes such as, "which area has temperature over 35ºC or 95ºF"**
- **A sensor has many functional components as shown in Figure 8.1**
- **A typical sensor consists of a transducer to sense a given physical quantity, an embedded processor, small memory and a wireless transceiver to transmit or receive data and an attached battery**

Functional Components: A Sensor



The Mica Mote

- The Mica Mote is a comprehensive sensor node developed by University of California at Berkeley and marketed by Crossbow
- It uses an Atmel Atmega 103 microcontroller running at 4 MHz, with a radio operating at the 916 MHz frequency band with bidirectional communication at 40 kbps when energized with a pair of AA batteries
- Mica Board is stacked to the processor board via the 51 pin extension connector to provide temperature, photo resistor, barometer, humidity, and thermopile sensors
- To conserve energy, later designs include an A/D Converter and an 8x8 power switch on the sensor board

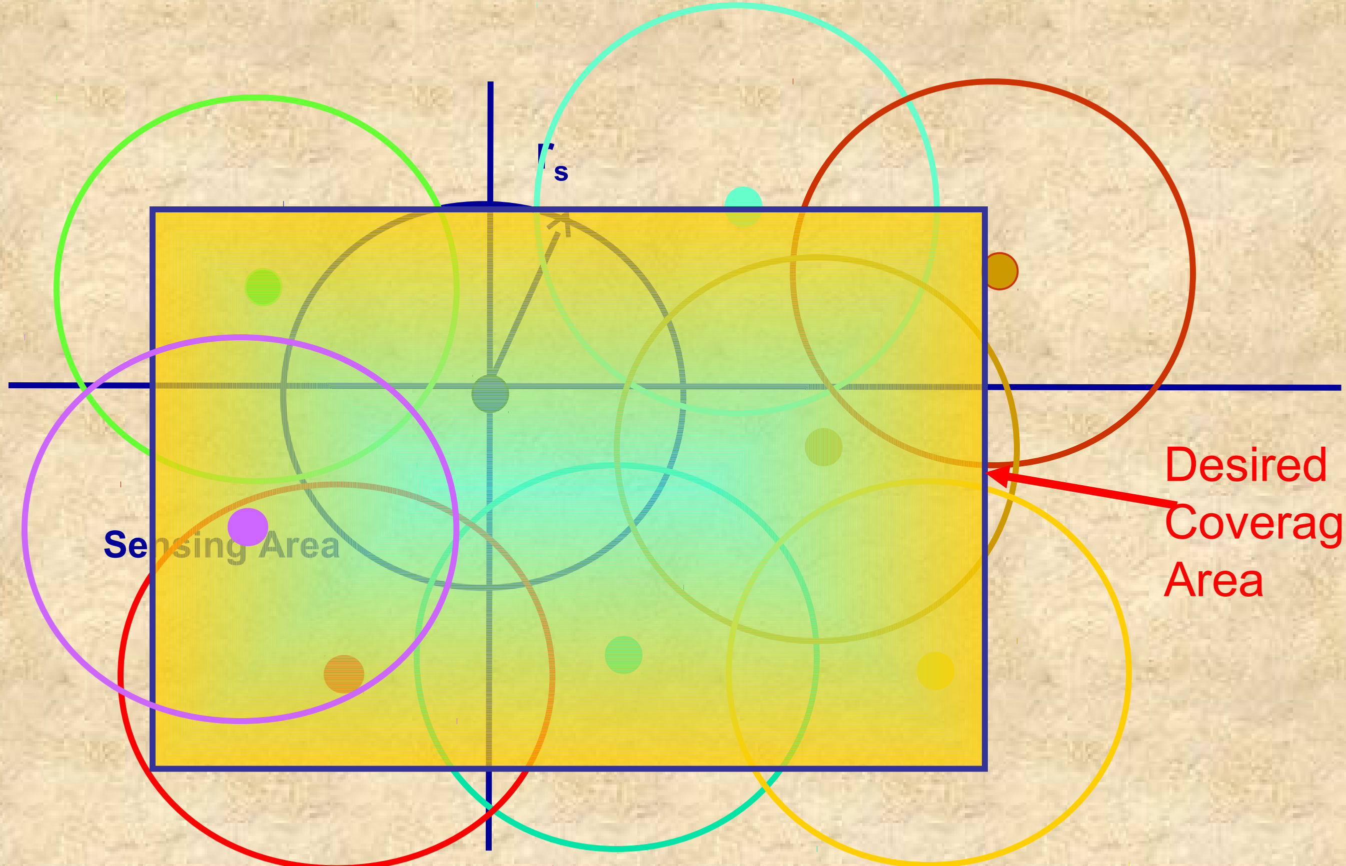
The Mica Mote

Mica Motes-2

Mica Board

Sensing and Communication Range

- A wireless sensor network (WSN) consists of a large number of sensor nodes (SNs)
- Adequate density of sensors is required so as to void any unsensed area



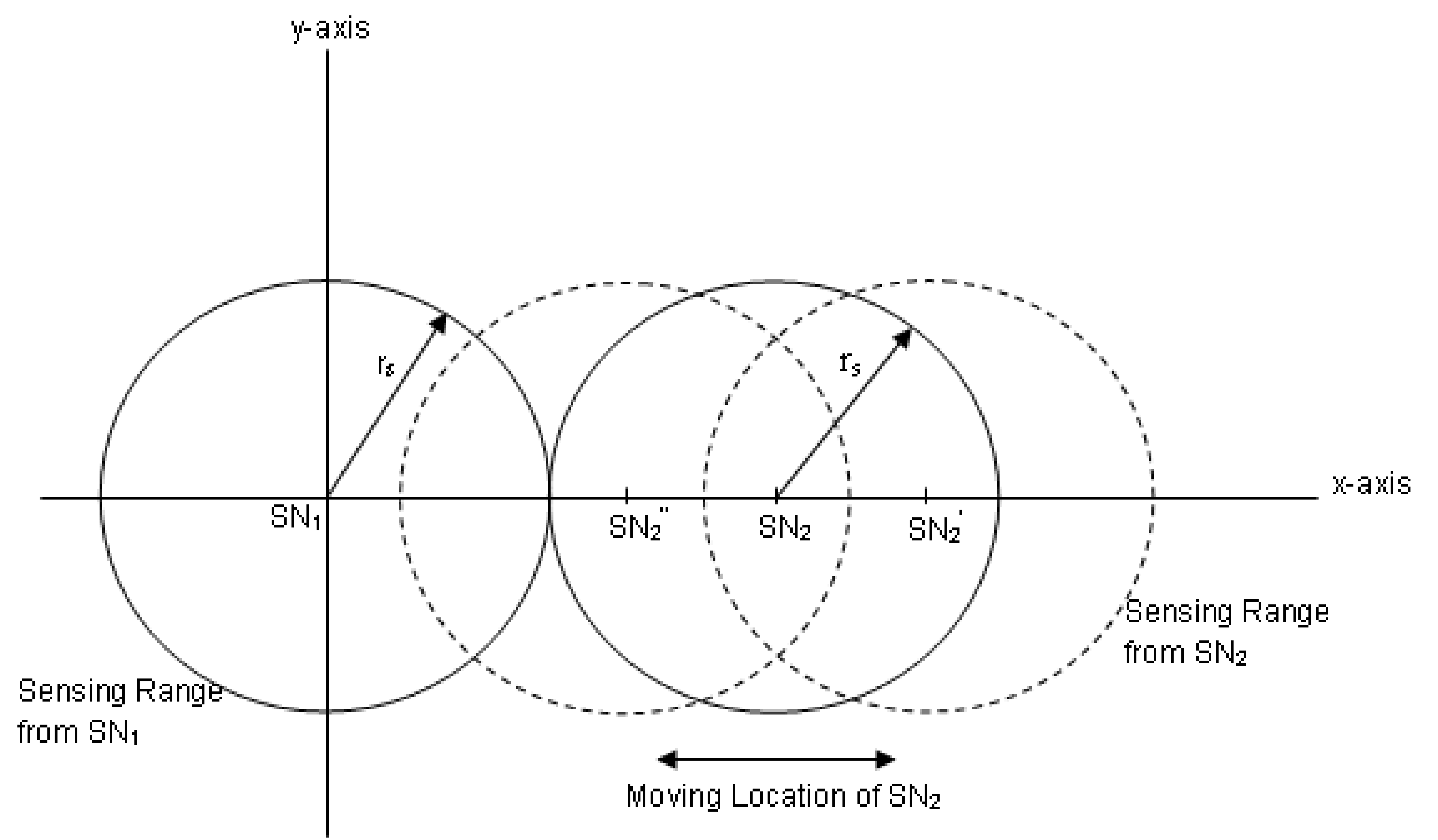
Sensing and Communication Range

- If N SNs are put in an area A, then the SNs density λ can be given by N/A
- The sensing range of each sensor is r_s
- To cover the whole space, adjacent SNs need to be located at most at a distance of $2r_s$ from each other
- If the SNs are uniformly distributed with the node density of λ, the probability that there are m SNs within the space of S is Poisson distributed as $P(m) = \frac{(\lambda S)^m}{m!} e^{-\lambda S}$

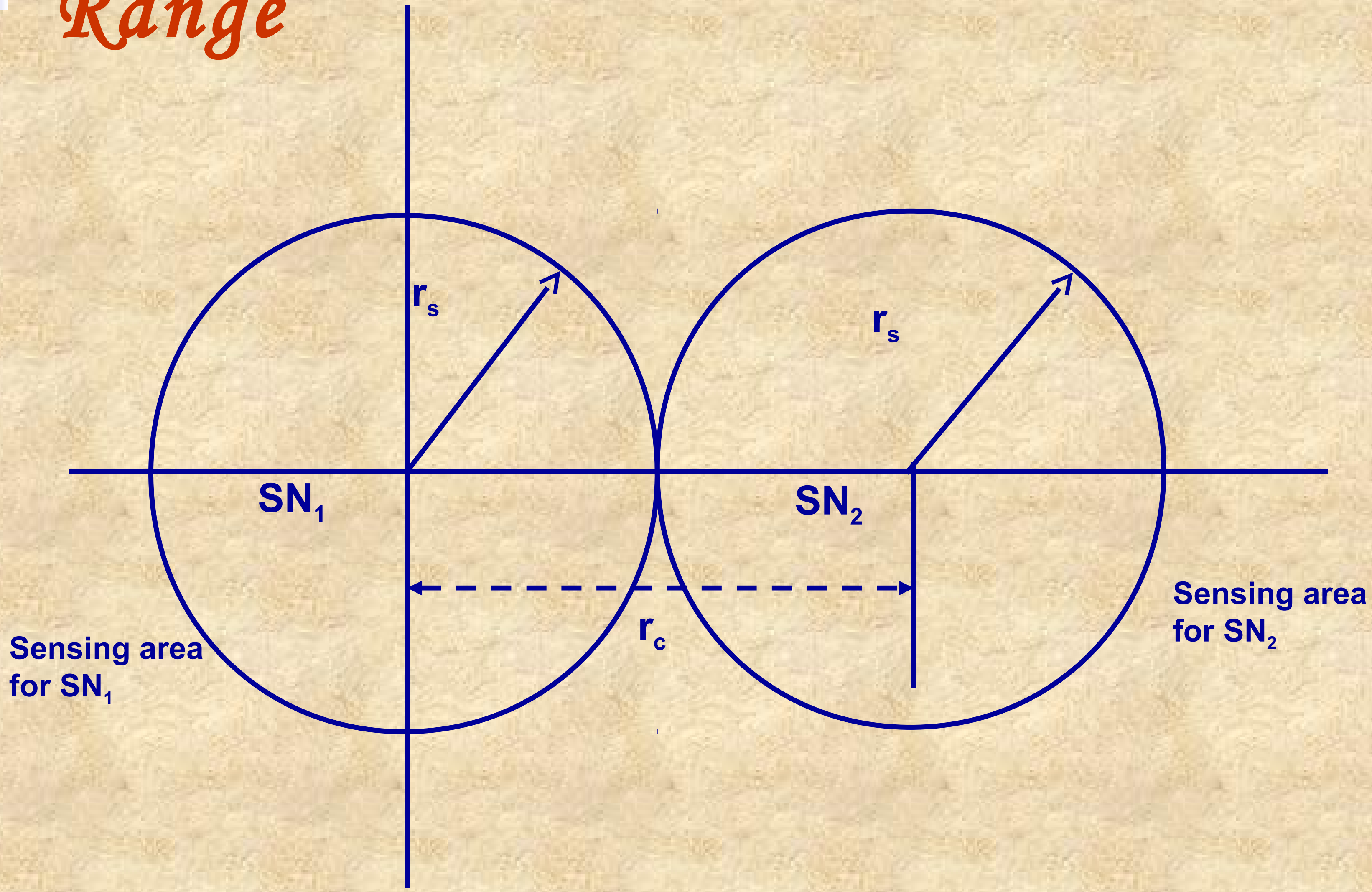
where space $S = \pi r_s^2$ for two dimensional spaces

- This gives the probability that the monitored space is not covered by any SN and hence the probability p_{cover} of the coverage by at least one SN is: $p_{cover} = 1 - P(0) = 1 - e^{-\lambda S}$

Sensing and Communication Range



Sensing and Communication Range



Sensing and Communication Range

- Transmission between adjacent SNs is feasible if there is at least one SN within the communication range of each SN
- Not just the sensing coverage, but the communication connectivity is equally important
- The wireless communication coverage of a sensor must be at least twice the sensing distance
- Data from a single SN is not adequate to make any useful decision and need to be collected from a set of SNs

Design Issues: Advantages of WSNs

- Ease of deployment – Can be dropped from a plane or placed in a factory, without any prior organization, thus reducing the installation cost and time, and increasing the flexibility of deployment

- Extended range – One huge wired sensor (macro-sensor) can be replaced by many smaller wireless sensors for the same cost

- Fault tolerant – With wireless sensors, failure of one node does not affect the network operation

- Mobility – Since these wireless sensors are equipped with battery, they can possess limited mobility (e.g., if placed on robots)

- Disadvatage: The wireless medium has a few inherent limitations such as low bandwidth, error prone transmissions, and potential collisions in channel access, etc.

Design Issues

Traditional routing protocols defined for MANETs are not well suited for wireless sensor networks due to the following reasons:

- Wireless sensor networks are "data centric", where data is requested based on particular criteria such as "which area has temperature 35ºC"
- In traditional wired and wireless networks, each node is given a unique identification and cannot be effectively used in sensor networks
- Adjacent nodes may have similar data and rather than sending data separately from each sensor node, it is desirable to aggregate similar data before sending it
- The requirements of the network change with the application and hence, it is application-specific

Desirable Features

- ***Attribute-based addressing*: This is typically employed in sensor networks where addresses are composed of a group of attribute-value pairs**
- ***Location awareness:* Since most data collection is based on location, it is desirable that the nodes know their position**
- **The sensors should react immediately to drastic changes in their environment**
- ***Query Handling*: Users should be able to request data from the network through some base station (also known as a sink) or through any of the nodes, whichever is closer**

Design Issues : Challenges

- **Routing protocol design is heavily influenced by many challenging factors**

- **These challenges can be summarized as follows:**

  - **Ad hoc deployment – Sensor nodes are randomly deployed so that they form connections between the nodes**

  - **Computational capabilities – Sensor nodes have limited computing power and therefore may run simple versions of routing protocols**

  - **Energy consumption without losing accuracy – Sensor nodes can use up their limited energy supply carrying out computations and transmitting information**

Design Issues : Challenges

- **Scalability** – The number of sensor nodes deployed in the sensing area may be in the order of hundreds, thousands, or more and routing scheme must be scalable enough to respond to events
- **Communication range** – The bandwidth of the wireless links connecting sensor nodes is often limited, hence constraining inter-sensor communication
- **Fault tolerance** – Some sensor nodes may fail or be blocked due to lack of power, physical damage, or environmental interference
- **Connectivity** – High node density in sensor networks precludes them from being completely isolated from each other

Design Issues : Challenges

- **Transmission media** –Communicating nodes are linked by a wireless medium and traditional problems associated with a wireless channel (e.g., fading, high error rate) also affect the operation
- **QoS** – In some applications (e.g., some military applications), the data should be delivered within a certain period of time from the moment it is sensed
- **Control Overhead** – When the number of retransmissions in wireless medium increases due to collisions, the latency and energy consumption also increases
- **Security** –Besides physical security, both authentication and encryption should be feasible while complex algorithm needs to be avoided

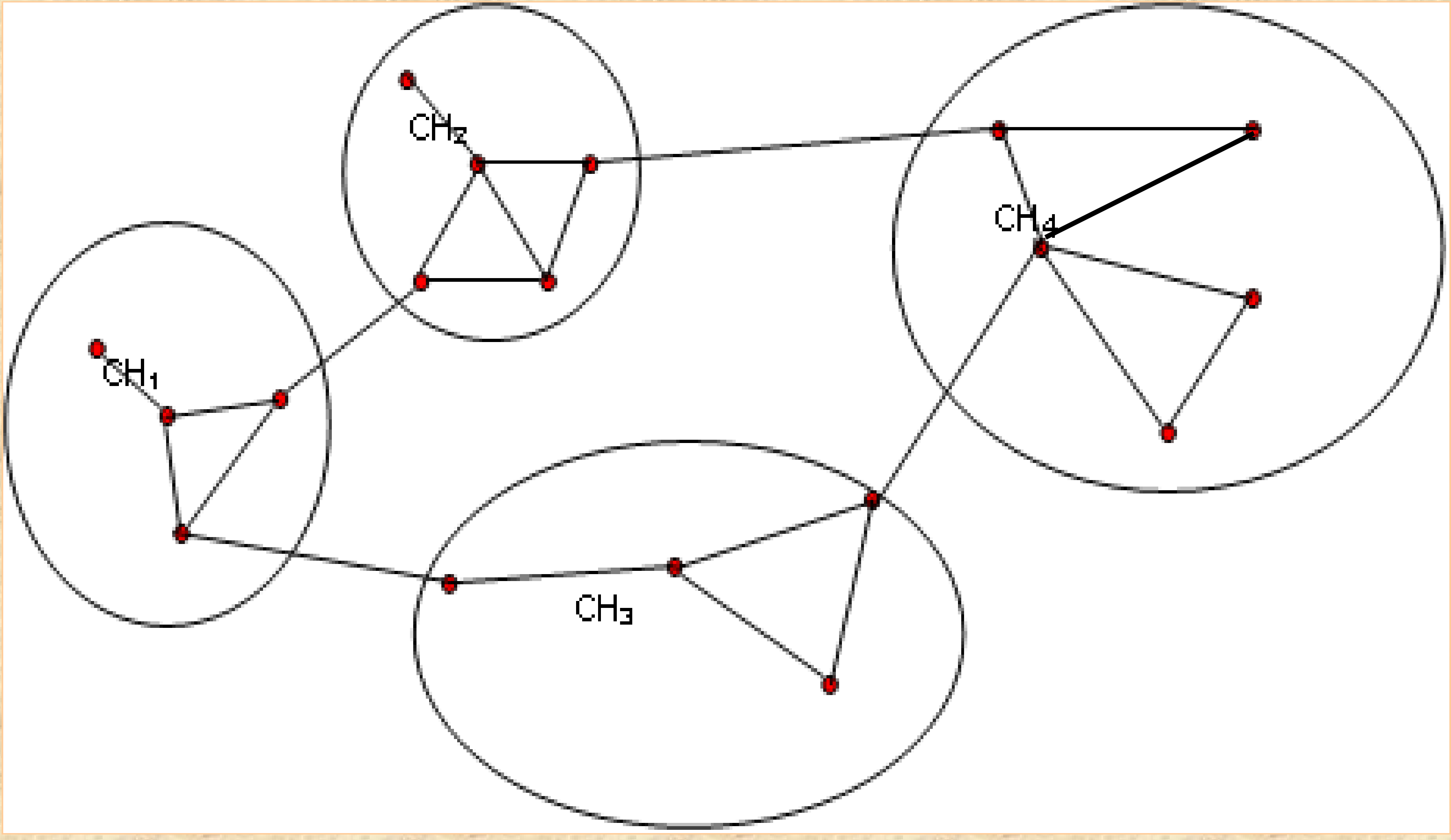
Energy Consumption

- Minimizing the energy consumption of WSs is critical yet a challenge for the design of WSNs
- Energy consumption in WSN involves three different components:
  - Sensing Transducer
  - A/D Converter (sensor consumes only 3.1 μW, in 31 pJ/8-bit sample at 1Volt supply, standby power consumption at 1V supply is 41pW, the lower bound on energy per sample is roughly $E_{min}= C_{total}V_{ref}^{2}$, where C_{total} is total capacitance of the array, and V_{ref} is input voltage
  - Transmission Energy, transmission energy transmits a k-bit message to distance d can be computed as: $E_{Tx}(k,d)=E_{Tx\text{-}elec}(k)+E_{Tx\text{-}amp}(k,d)=E_{elec}*k+*k*d^{2}$, where $E_{Tx\text{-}elec}$ is the transmission electronics energy consumption, $E_{Tx\text{-}amp}$ is the transmit amplifier energy consumption, example values: $E_{Tx\text{-}elec}=E_{Rx\text{-}elec}=E_{elec}$=50nJ/bit, ε_{amp} =100pJ/bit/m²
  - Receiver Energy, $E_{Rx}(k)=E_{Rx\text{-}elec}(k)=E_{elec}*k$
  - Computing/Processing Unit, $E_{switch}=C_{total}V_{dd}^{2}$
- In order to conserve energy, we may make some SNs go to sleep mode and need to consider energy consumed in that state
- Sensing transducer is responsible for capturing the physical parameters of the environment

Energy Consumption : Clustering of SNs

- **Clustering of SNs not only allows aggregation of sensed data, but limits data transmission primarily within the cluster**
- **The sequence starts with discovery of neighboring SNs by sending periodic Beacon Signals, determining close by SNs with some intermediate SNs, forming clusters and selecting cluster head (CH) for each cluster**
- **So, the real question is how to group adjacent SNs, and how many groups should be there that could optimize some performance parameter**
- **One approach is to partition the WSN into clusters such that all members of the clusters are directly connected to the CH**
- **One such example for randomly deployed SNs**
- **SNs in a WSN in a cluster, can transmit directly to the CH without any intermediate SN**

Energy Consumption : Clustering of SNs



Clustering of Sensors

- Data from SNs belonging to a single cluster can be combined together in an intelligent way (aggregation) using local transmissions

- This can not only reduce the global data to be transferred and localized most traffic to within each individual cluster

- A lot of research gone into testing coverage of areas by **k-sensors** clustering adjacent SNs and defining the size of the cluster so that the cluster heads (CHs) can communicate and get data from their own cluster members

- If each cluster is covered by more than one subset of SNs all the time, then some of the SNs can be put into sleep mode so as to conserve energy while keeping full coverage

- The use of a second smaller radio has been suggested for waking up the sleeping sensor, thereby conserving the power of main wireless transmitter

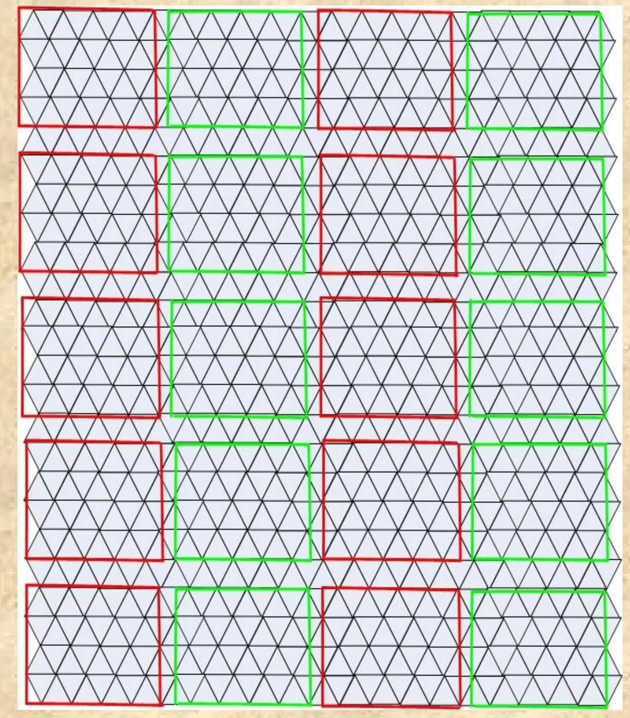
Clustering of Sensors: Predetermined Grid v/s Random Placement

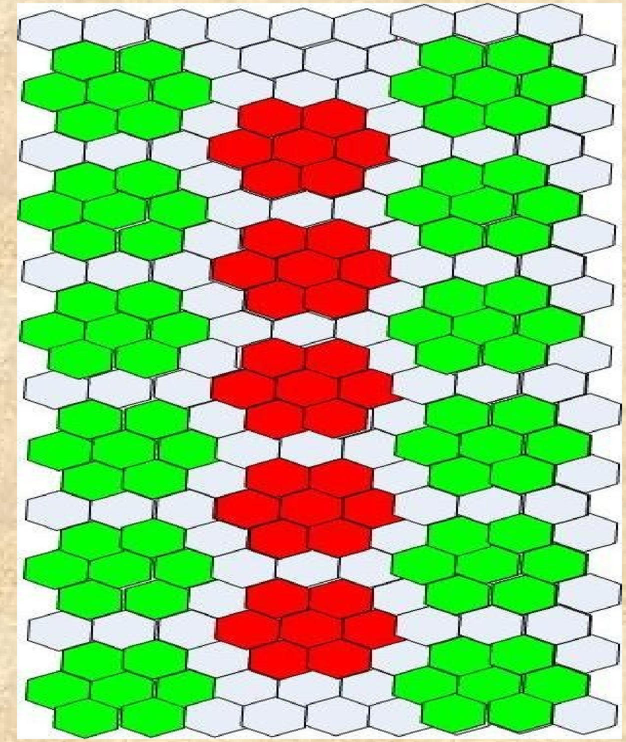
Regularly placed sensors

- A simple strategy is to place the sensors in the form of two-dimensional grid as such cross-point and such configuration may be very useful for uniform coverage
- Such symmetric placement allows best possible regular coverage and easy clustering of the close-by SNs
- Three such examples of SNs in rectangular, triangular and hexagonal tiles of clusters are shown

Regularly Placed Sensors

Useful for deploying in a controlled environment



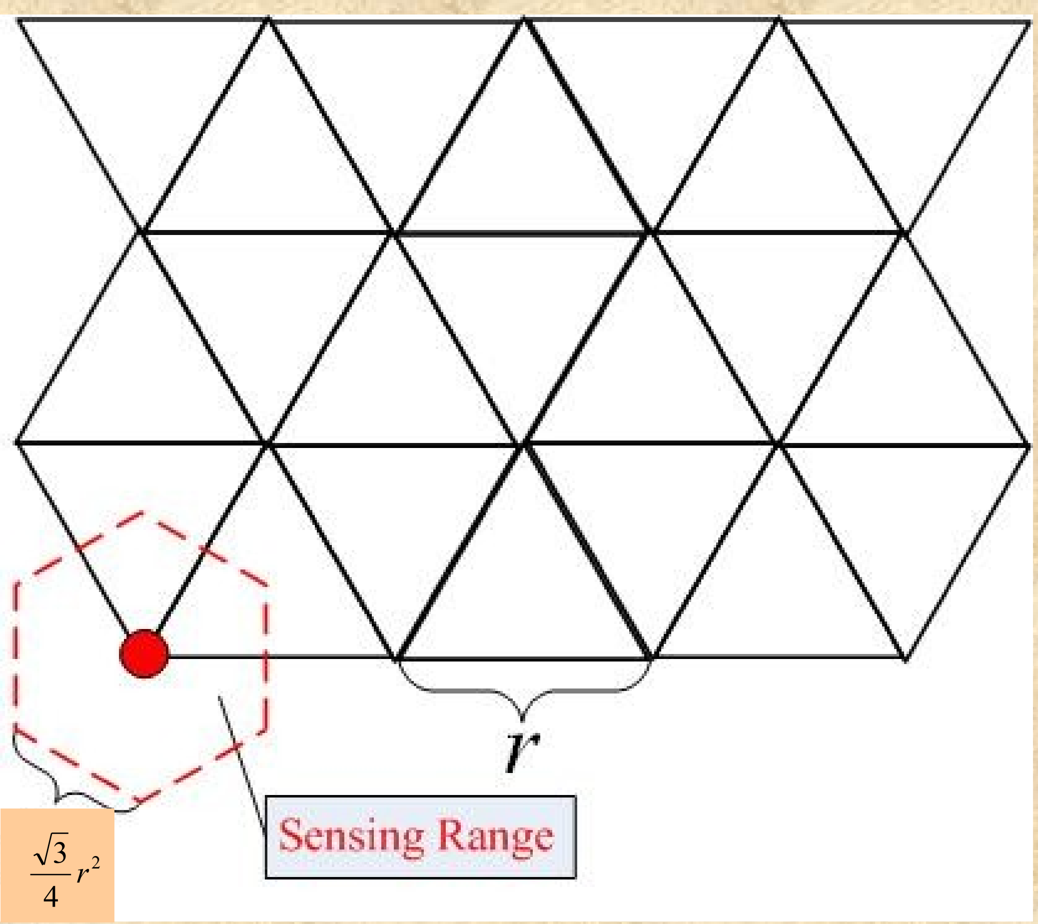


- **Clusters of size 5x5, with a SN located at each intersection of lines**
- **Square, triangle, or hexagonal placement of the SNs also dictates the minimum sensing area that need to be covered by each sensor**

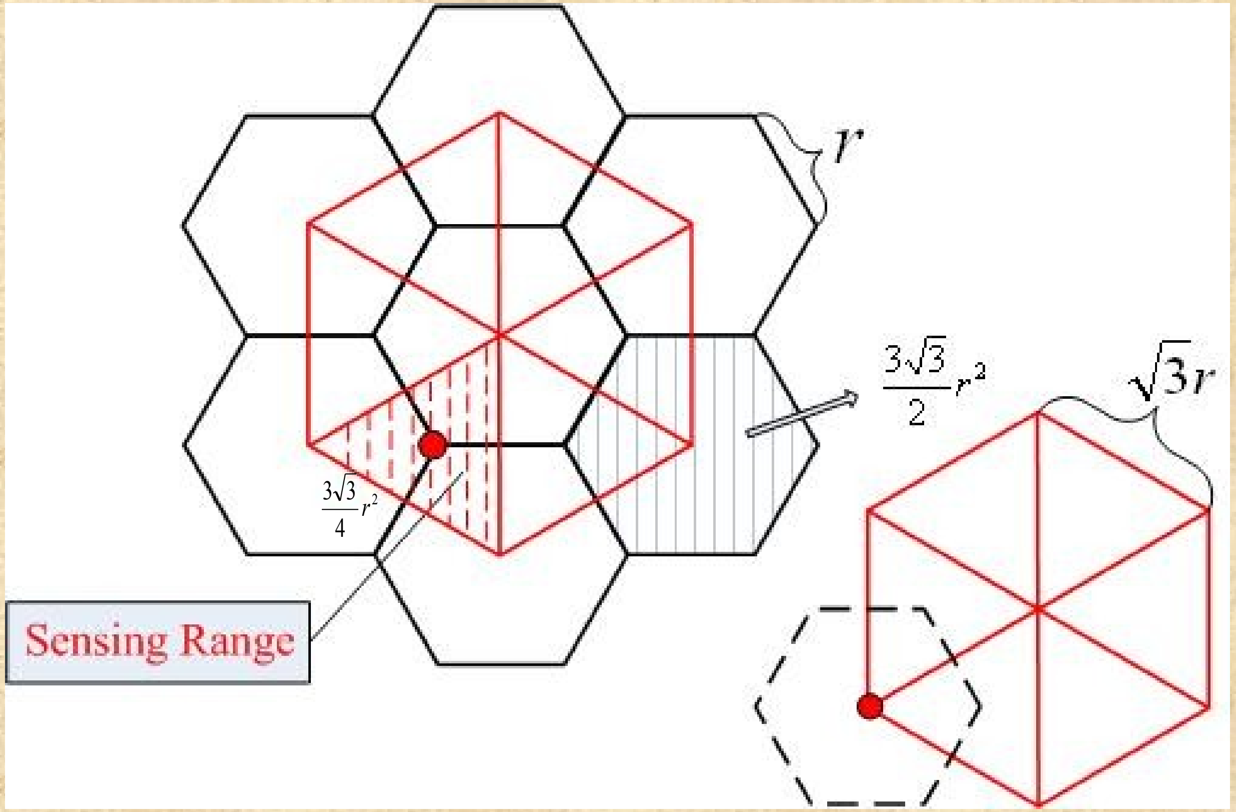
Regularly placed sensors

- Detailed views of three different configurations, are shown in next three slides
- For simplicity of calculation, the sensing area covered by rectangular placement is taken rectangular, while sensing are by the two configurations are assumed hexagonal and triangular respectively
- The required number of SNs in each scheme, is given in Table 8.2
- Radio transmission distance between adjacent SNs need to be such that the sensors can receive data from adjacent sensors using wireless radio
- Clustering can be done for these configurations and the size of each cluster can be fixed as per application requirements
- If the sensing and radio transmission ranges are set to the minimum value, then all the SNs need to be active all the time to cover the area and function properly
- If these ranges are increased, then each sub-region can be covered by more than one sensor node and selected SNs can be allowed to go to sleep mode

Triangular Placed Sensors

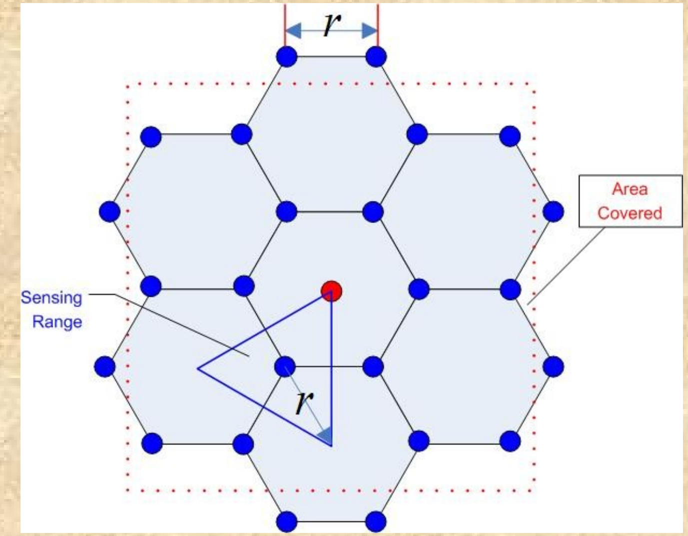


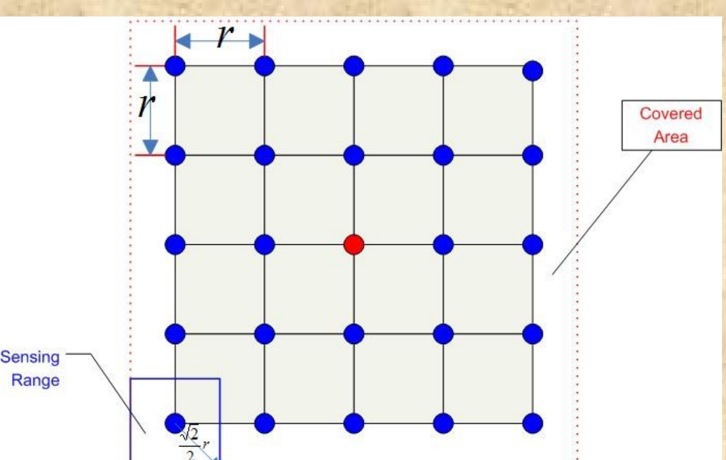
Hexagonal Placed Sensors

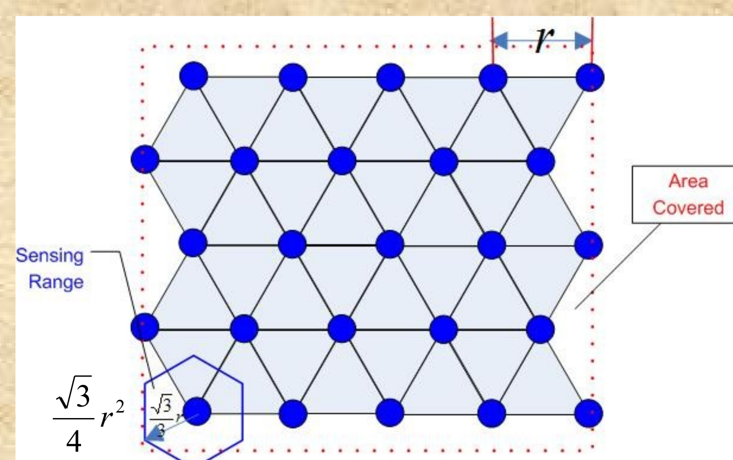


Regularly Placed Sensors

$$\frac{3\sqrt{3}}{4}r^2$$







Placement of Sensors and Covered Sensing Area

Placement	Distance Between Adjacent Sensors	Sensing Area to be covered by each sensor	Total sensing area covered by N-Sensors
Rectangular			
Triangular			
Hexagon			

Randomly distributed sensors

- **The sensors could also be used in an unknown territory or inaccessible area by deploying them from a low flying airplane or unmanned ground/aerial vehicle**
- **SNs have to find themselves who their communicating neighbors are and how many of them are present**
- **The adjacency among SNs can be initially determined by sending bacon signals as is done in a typical ad hoc network (MANET)**
- **The communication range of associated wireless radio should be such that the SNs could be connected together to form a WSN**
- **Distribution of the SNs and their sensing range would also determine if the physical parameter in the complete deployed area can be sensed by at least one SN**

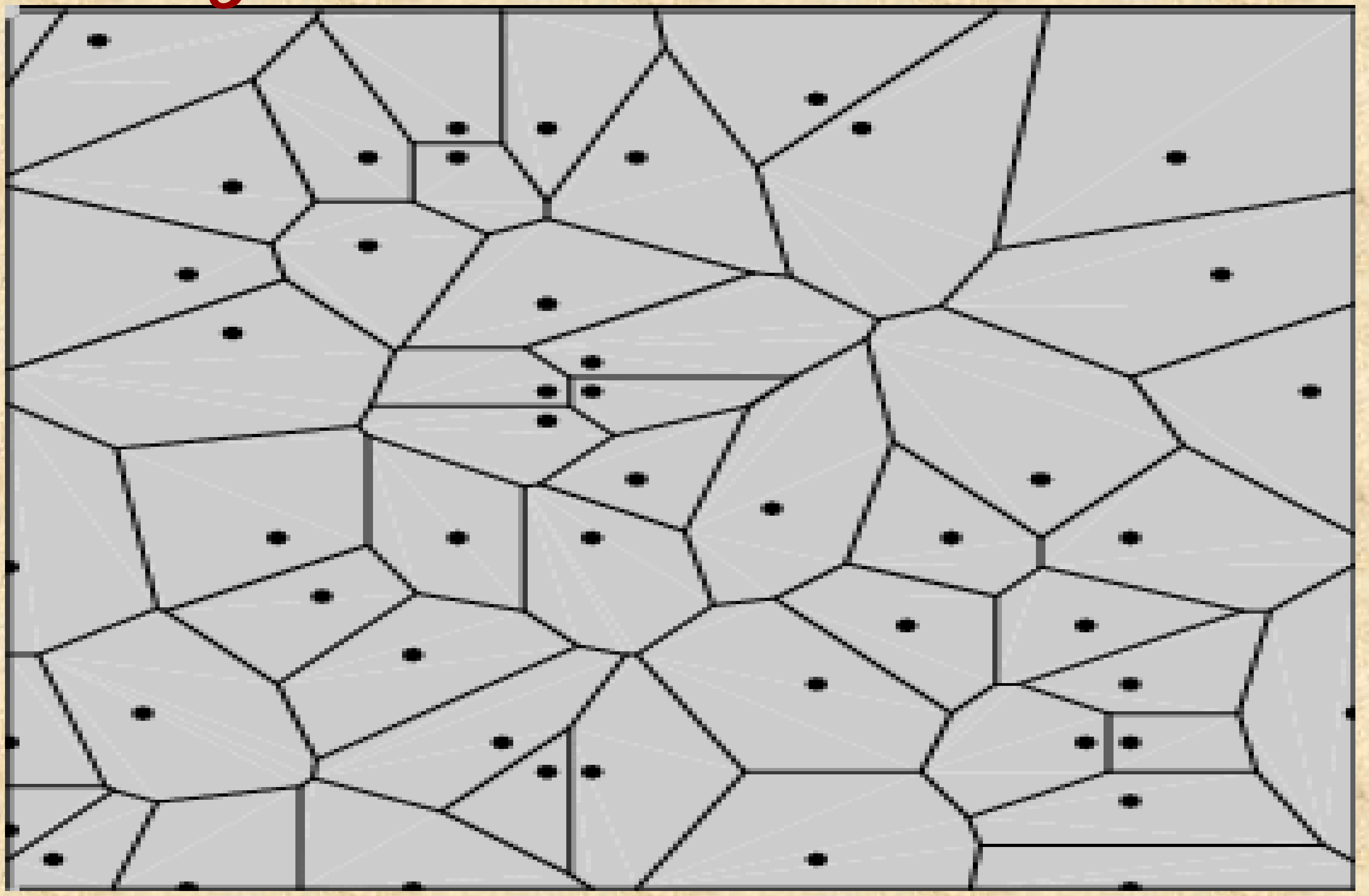
Randomly Distributed Sensors

- The sensing and communication ranges required in a randomly placed sensor are governed by the maximum distance to be covered by any one of the sensors in the given area
- If the N-nodes are uniformly distributed in an area A=LxL, then the node density can be given by $\lambda = N / A$
- The probability that there are m nodes within the area S, is Poisson distributed and can be given by : $P(m) = \frac{(\lambda S)^m}{m!} e^{-\lambda S}$
- The probability that the monitored area or space is 1-covered, can be expressed as : $p_{1-covered} = 1 - P(0) = 1 - e^{-\lambda S}$
- In many situations, an event need to be sensed by at least k close-by sensors for a cooperative decision (such as relative location using triangulation), then concurrent sensing by k SNs can be given by

$$p_{k-covered} = 1 - \sum_{m=0}^{k-1} P(m) = 1 - \sum_{m=0}^{k-1} \frac{(\lambda S)^m}{m!} e^{-\lambda S}$$

- One way to determine the area to be covered by each SN is to form a Voronoi diagram and one such example is shown in Figure 8.10
- The basic idea is to partition the area in to a set of convex polygons such that all polygons edges are equidistant from neighboring sensors
- A simplistic approach is to let each sensor at least sense the area covered by its surrounding polygon and maximum distance to be covered by a SN in a polygon will govern the required sensing area
- Similarly, minimum wireless transmission range can be determined by the maximum distance between any pair of adjacent sensors

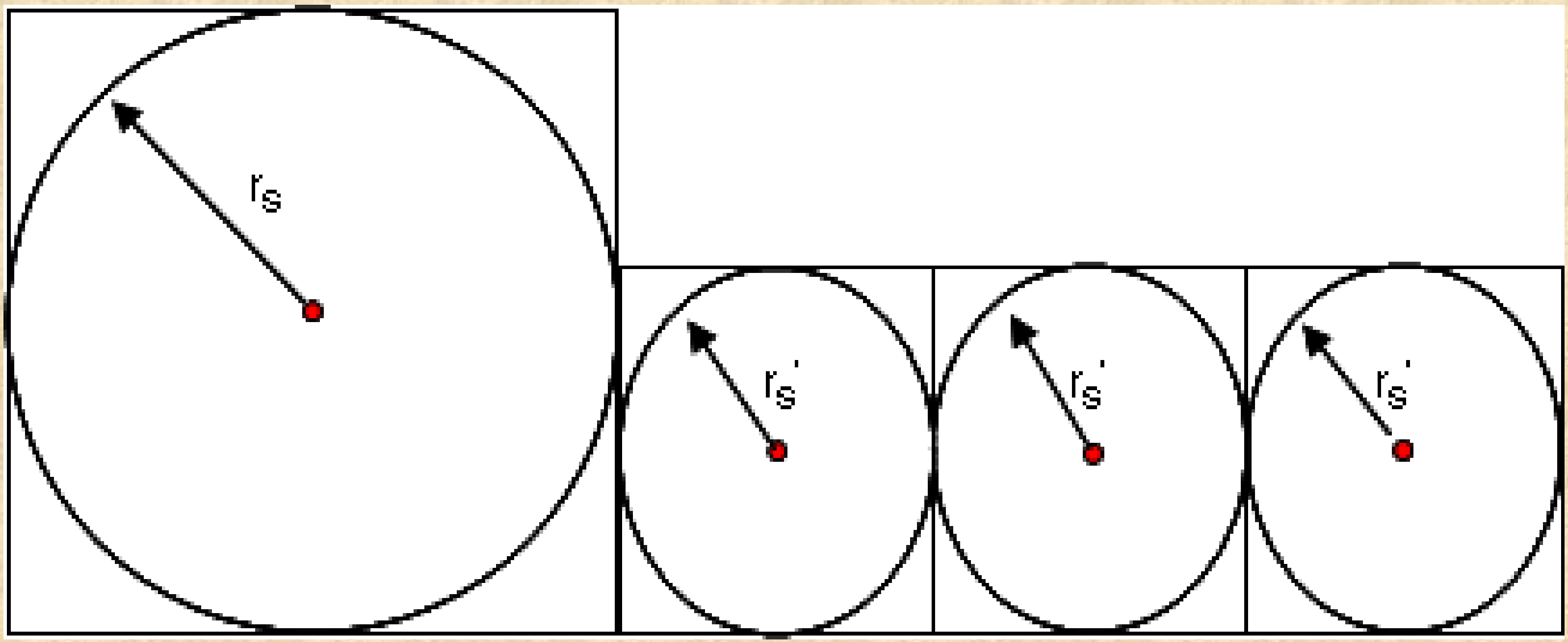
Randomly Distributed Sensors: Voronoi diagram



Heterogeneous WSNs

- With constant sensing and transmission range for all SNs, WSNs are also known as homogeneous WSNs
- This makes the design simpler and easier to manage
- In some situations, when a new version of SNs are deployed to cover additional area, or some of the existing SNs are replaced by new ones for extended life or precision, then sensing and/or communication range and/or computing power may also depend on the sensor type or version
- Use of sensors with different sensing and/or communication and/or computation capabilities leads to a heterogeneous WSN which is helpful for performing additional functionalities or be given much more responsibilities
- One such example is shown in Figure 8.11

Heterogeneous WSNs



Mobile Sensors

- **The enhancements in the field of robotics are paving the way for industrial robots to be applied to a wider range of tasks**
- **However, harnessing their full efficiency also depends on how accurately they understand their environment**
- **Thus, as sensor networks are the primary choice for environmental sensing, combining sensor networks with mobile robots is a natural and very promising application**
- **Robots could play a major role of high-speed resource carriers in defense and military applications where human time and life is very precious**
- **Other applications include fire fighting, autonomous waste disposal**
- **Thus, we see that there are a number of future applications where sensors and robots could work together through some form of cooperation**

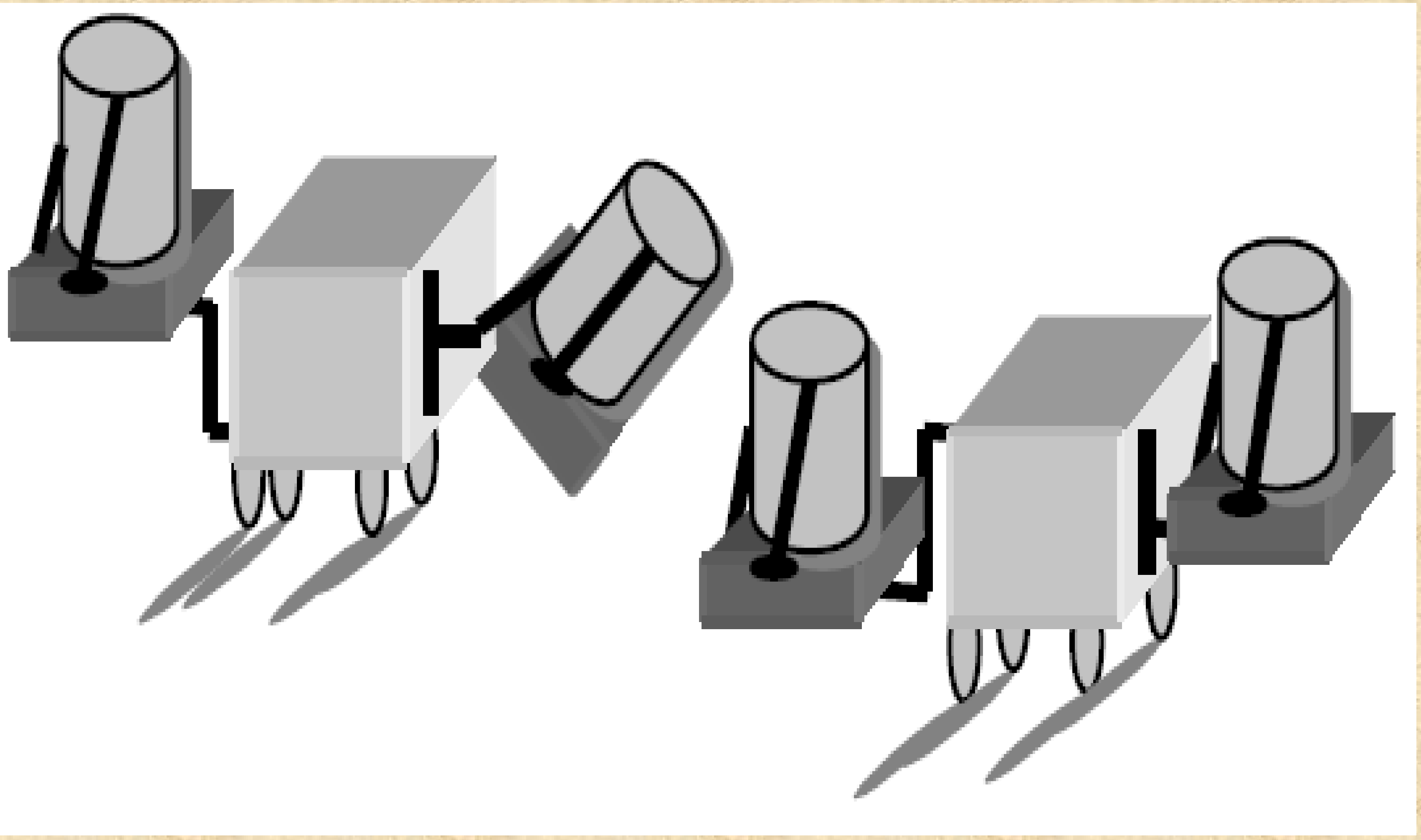
Mobile Sensors

- **Sensors detect events autonomously and the mobile robots could take appropriate actions based on the nature of the event**
- **Coordination between the mobile robots is obviously critical in achieving better resource distribution and information retrieval**
- **Mobile sensor Networks have been suggested to cover the area not reachable by static sensors**
- **Coordination between multiple robots for resource transportation has been explored for quite some time now**
- **Transporting various types of resources for different applications like defense, manufacturing process, and so on, has been suggested**
- **In these schemes, time taken to detect an event depends entirely on the trail followed by the robots**
- **Though the path progressively gets better with the use of an ant-like type of algorithm, the whole process has to be started anew when the position of the event changes**

Mobile Sensors

- In terrains where human ingress is difficult, mobile robots can be used to imitate the human's chore
- Typical resource-carrying robots are depicted in Figure 8.12 which depicts a possible means of a robot transferring its resources to anothers
- Once depleted of their resource, they may get themselves refilled from the sink
- The resource in demand could be water or sand (to extinguish fire), oxygen supply, medicines, bullets, clothes or chemicals to neutralize hazardous wastes, and so on
- The target region that is in need of these resources is sometimes called an event location
- Whether it is a sensor or another robot within collision distance, it is considered an obstacle and the robot proceeds in a direction away from it

Mobile Sensors



Applications

- Thousands of sensors over strategic locations are used in a structure such as an automobile or an airplane, so that conditions can be constantly monitored both from the inside and the outside and a real-time warning can be issued whenever a major problem is forthcoming in the monitored entity
- These wired sensors are large (and expensive) to cover as much area is desirable
- Each of these need a continuous power supply and communicates their data to the end-user using a wired network
- The organization of such a network should be pre-planned to find strategic position to place these nodes and then should be installed appropriately
- The failure of a single node might bring down the whole network or leave that region completely un-monitored

Applications

- Unattendability and some degree of fault tolerance in these networks are desirable in those applications where the sensors may be embedded in the structure or places in an inhospitable terrain and could be inaccessible for any service
- Undoubtedly, wireless sensor networks have been conceived with military applications in mind, including battlefield surveillance and tracking of enemy activities
- However, civil applications considerably outnumber the military ones and are applicable to many practical situations
- Judging by the interest shown by military, academia, and the media, innumerable applications do exist for sensor networks
- Examples include weather monitoring, security and tactical surveillance, distributed computing, fault detection and diagnosis in machinery, large bridges and tall structures, detecting ambient conditions such as temperature, movement, sound, light, radiation, vibration, smoke, gases, or the presence of certain biological and chemical objects

Applications

- Under the civil category, envisioned applications can be classified into environment observation and forecast system, habitat monitoring equipment and human health, large structures and other commercial applications

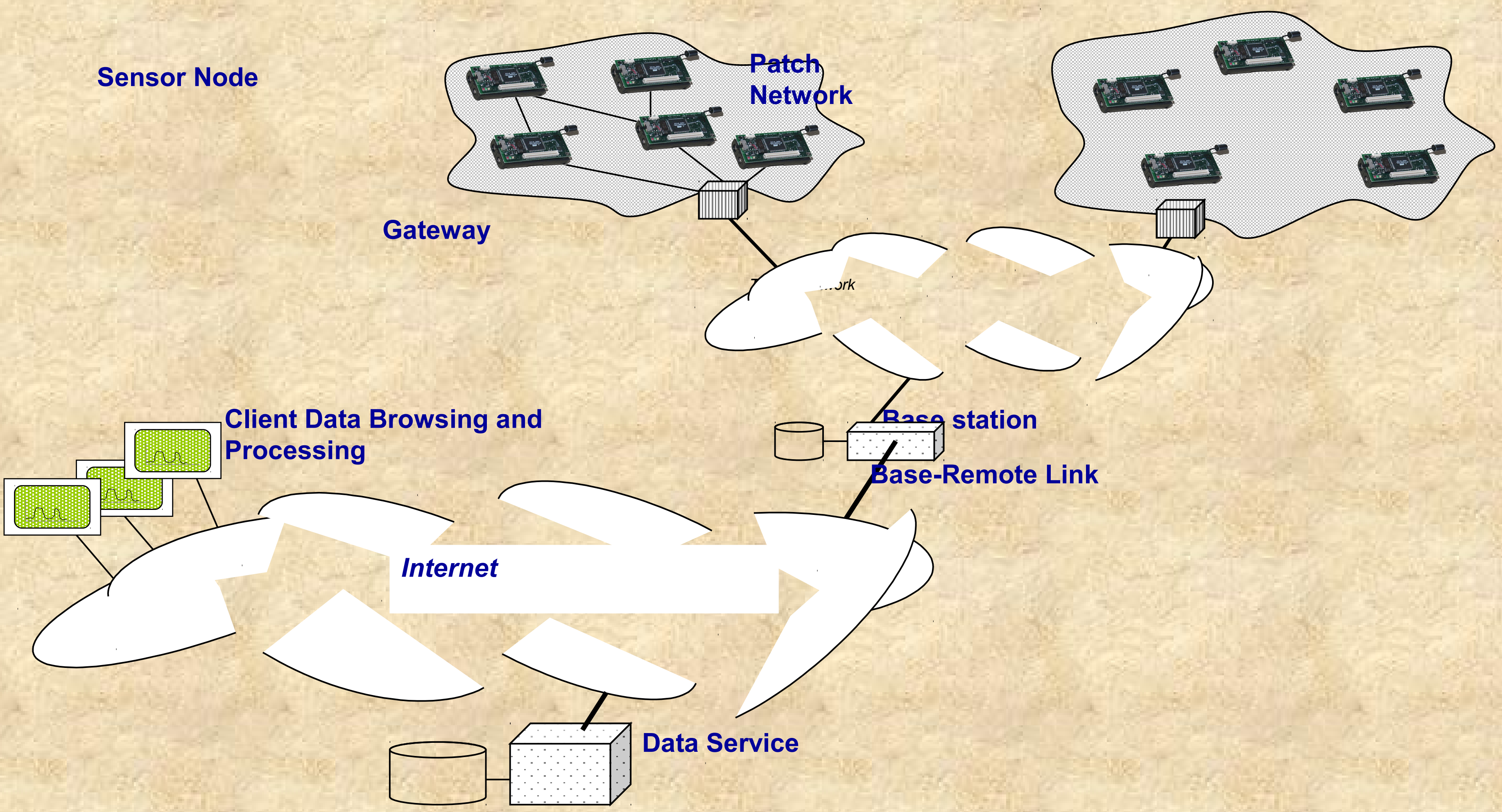
Habitat Monitoring

- A prototype test bed consisting of iPAQs (i.e., a type of handheld device) has been built to evaluate the performance of these target classification and localization methods
- As expected, energy efficiency is one of the design goals at every level: hardware, local processing (compressing, filtering, etc.), MAC and topology control, data aggregation, data-centric routing and storage
- Preprocessing is proposed in for habitat monitoring applications, where it is argued that the tiered network in GDI is solely used for communication
- The proposed 2-tier network architecture consists of micro nodes and macro nodes, wherein the micro nodes perform local filtering and data to significantly reduce the amount of data transmitted to macro nodes

Applications The Grand Duck Island Monitoring Network

- Researchers from the University of California at Berkeley (UCB) and Intel Research Laboratory deployed in August 2002 a mote-based tiered sensor network in Great Duck Island (GDI), Maine, aimed at monitoring the behavior of storm petrel
- The overall system architecture is depicted in Figure 8.13
- A total of 32 motes have been placed in the area to be sensed grouped into sensor patches to transmit sensed data to a gateway which is responsible for forwarding the information from the sensor patch to a remote base station through a local transit network
- The base station then provides data logging and replicates the data every 15 minutes to a database in Berkeley over a satellite link
- Remote users can access the replica database server in Berkeley, while local users make use of a small PDA-size device to perform local interactions such as adjusting the sampling rates, power management parameters, etc.

The Grand Duck Island Monitoring Netwo



Applications: Remote Ecological Micro-Sensor Network

- PODS is a research project undertaken at the University of Hawaii that has built a wireless network of environmental sensors to investigate why endangered species of plants will grow in one area but not in neighboring areas
- They deployed camouflaged sensor nodes, (called PODS), in the Hawaii Volcanoes National Park
- The PODS consist of a computer, radio transceiver and environmental sensors, sometimes including a high resolution digital camera, relaying sensed data via wireless link back to the Internet
- Bluetooth and 802.11b are chosen as the MAC layer, while data packets are delivered through the IP
- In PODS, energy efficiency is identified as one of the design goals and an ad hoc routing protocols called Multi-Path On-demand Routing (MOR) has been developed

Applications: Remote Ecological Micro-Sensor Network

- **Weather data are collected every ten minutes and image data are collected once per hour**
- **Users employ the Internet to access the data from a server in University of Hawaii at Manoa**
- **The placement strategy for the sensor nodes is then investigated**
- **Topologies of 1-dimensional and 2-dimensional regions such as triangle tile, square tile, hexagon tile, ring, star, and linear are discussed**
- **The sensor placement strategy evaluation is based on three goals: resilience to single point of failure, the area of interest has to be covered by at lease one sensor, and minimum number of nodes**
- **Finally, it is found that the choice of placement depends on d and r**

Environmental Monitoring Application

- **Sensors to monitor landfill and the air quality**

- **Household solid waste and non-hazardous industrial waste such as construction debris and sewer sludge are being disposed off by using over 6000 landfills in USA and associated organic components undergo biological and chemical reaction such as fermentation, biodegradation and oxidation-reduction**

- **This causes harmful gases like methane, carbon dioxide, nitrogen, sulfide compounds and ammonia to be produced and migration of gases in the landfill causes physical reactions which eventually lead to ozone gases, a primary air pollutant and an irritant to our respiratory systems**

- **The current method of monitoring landfill employs periodic drilling of collection well, collecting gas samples in airtight bags and analyze off-site, making the process very time consuming**

Environmental Monitoring Application

- **The idea is to interface gas sensors with custom-made devices and wireless radio and transmit sensed data for further analysis**
- **Deployment of a large number of sensors allows real-time monitoring of gases being emitted by the waste material or from industrial spills**
- **Place a large number of sensors throughout the area of interest and appropriate type of sensors can be placed according to the type of pollutant anticipated in a given area**
- **A large volume of raw data from sensors, can be collected, processed and efficiently retrieval**
- **A generic set up of a WSN, has been covered and various associated issues have been clearly pointed out**
- **The scheme can be easily used and adopted for other applications as well**

Environment Observation and Forecasting System

- The Environment Observation and Forecasting System (EOFS) is a distributed system that spans large geographic areas and monitors, models and forecasts physical processes such as environmental pollution, flooding, among others

- Usually, it consists of three components: sensor stations, a distribution network, and a centralized processing farm

- Some of the characteristics of EOFS are:
  - Centralized processing: The environment model is computationally very intensive and runs on a central server and process data gathered from the sensor network
  - High data volume: For example, nautical X-band radar can generate megabytes of data per second
  - QoS sensitivity: This defines the utility of the data and there is an engineering trade-off between QoS and energy constraint
  - Extensibility
  - Autonomous operation

Drinking Water Quality

- **A sensor based monitoring system with emphasis on placement and utilization of in situ sensing technologies and doing spatial-temporal data mining for water-quality monitoring and modeling**
- **The main objective is to develop data-mining techniques to water-quality databases and use them for interpreting and using environmental data**
- **This also helps in controlling addition of chlorine to the treated water before releasing to the distribution system**
- **Detailed implementation of a bio-sensor for incoming wastewater treatment has been discussed**
- **A pilot-scale and full scale system has also been described**

Disaster Relief Management and Soil Moisture Monitoring

- Novel sensor network architecture has been proposed in that could be useful for major disasters including earthquakes, storms, floods, fires and terrorist attacks

- The SNs are deployed randomly at homes, offices and other places prior to the disaster and data collecting nodes communicate with database server for a given sub area which are in-turn linked to a central database for continuous update

Soil Moisture Monitoring

- A soil moisture monitoring scheme using sensors, over a one hectare outdoor area and various performance parameters measured from an actual system

- A custom made moisture sensor is interfaced with Mica-2 Mote wireless board

Health Care Monitoring

- Telemonitoring of human physiological data, tracking and monitoring of doctors and patients inside a hospital, drug administrator in hospitals, …
- An example: Artificial retina developed within the Smart Sensors and Integrated Microsystems (SSIM) project
- A retina prosthesis chip consisting of one hundred microsensors are built and implanted within the human eye, allowing patients with no vision or limited vision to see at an acceptable level
- Wireless communication is required to suit the need for feedback control, image identification and validation
- The communication pattern is deterministic and periodic like a TDMA scheme

Building, Bridge and Structural Monitoring

- **Projects have explored the use of sensors in monitoring the health of buildings, bridges and highways**
- **A Bluetooth based scatternet has been proposed to monitor stress, vibration, temperature, humidity etc. in civil infrastructures**
- **Simulation results are given to justify effectiveness of their solution by having a set of rectangular Bluetooth equipped sensor grids to model a portion of bridge span**
- **Fiber optic based sensors have been proposed for monitoring crack openings in concrete bridge decks, of strain and corrosion of the reinforcement in concrete structures**
- **Corrosion of steel bars is measured by using special super glue and angular strain sensors**

Smart Energy and Home/Office Applications

- Societal-scale sensor networks can greatly improve the efficiency of energy-provision chain, which consists of three components: the energy-generation, distribution, and consumption infrastructure
- It has been reported that 1% load reduction due to demand response can lead to a 10% reduction in wholesale prices, while a 5% load response can cut the wholesale price in half

DARPA Efforts towards Wireless Sensor Networks

- The DARPA has identified networked micro sensors technology as a key application for the future
- On the battlefield of the future, a networked system of smart, inexpensive and plentiful microsensors, combining multiple sensor types, embedded processors, positioning ability and wireless communication, will pervade the environment and provide commanders and soldiers alike with heightened situation awareness

Body Area Network

- **Specialized sensors and transducers are being developed to measure human body characterizing parameters**
- **There has been increased interest in the biomedical area and numerous proposals have recently been introduced**
- **Micro sensor array is used for artificial retina, glucose level monitoring, organ monitors, cancer detectors and general health monitoring**
- **A wearable computing network has been suggested to remotely monitor the progress of a physical therapy done at home and an initial prototype has been developed using electroluminescent strips indicating the range of human body's motion**
- **An indoor/outdoor wearable navigation system has been suggested for blind and visually impaired people through vocal interfaces about surrounding environment and changing the mode from indoor to outdoor and vice-versa using simple vocal command**

Conclusions and Future Directions

- **Sensor networks are perhaps one of the fastest growing areas in the broad wireless ad hoc networking field**

- **As we could see throughout this chapter, the research in sensor networks is flourishing at a rapid pace and still there are many challenges to be addressed such as:**
  - **Energy Conservation - Nodes are battery powered with limited resources while still having to perform basic functions such as sensing, transmission and routing**
  - **Sensing - Many new sensor transducers are being developed to convert physical quantity to equivalent electrical signal and many new development is anticipated**
  - **Communication - Sensor networks are very bandwidth-limited and how to optimize the use of the scarce resources and how can sensor nodes minimize the amount of communication**
  - **Computation - Here, there are many open issues in what regards signal processing algorithms and network protocols**